Ceramics International **24** (1998) 533–542
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PII: S0272-8842(97)00053-9
0272-8842/98 $19.00+.00

Wet Erosive Wear of Alumina and its Composites with SiC Nano-particles

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(Received 19 March 1997; accepted 29 May 1997)

Abstract: A study of the room temperature controlled wet erosive wear of monolithic alumina and its composites with nano-sized particles of SiC is presented. The worn surfaces suggest that grain pull-out phenomenon is the dominant mechanism determining the wear rate. Within the composites, a higher strength does not necessarily translate into a higher wear rate. Wet erosive wear depends on grain size, porosity, volume fraction of SiC particles in the composites and possibly the morphology of the grains (for monolithic alumina). For very nearly fully dense materials of about the same grain size, the composites are about 200% more wear-resistant than monolithic alumina. About 5% porous composites are at least 400% more wear-resistant than monolithic alumina of the same level of porosity. © 1998 Elsevier Science Limited and Techna S.r.l.

1 INTRODUCTION

Wet erosion wear resistance is an important property of systems that deal with the transportation of particulate slurries. Lining the parts (of the system) in direct contact with the slurries with alumina (due to its hardness) could lead to higher productivity and more cost-effectiveness.[1] The wet-erosive wear resistance of monolithic alumina is improved[2–4] by reducing the latter's grain size. It has been suggested[5] that high aspect ratios (for a limited number of grains within a microstructure) are desirable in materials destined for enhanced flaw tolerance. Most of the results on the wet-erosive wear of alumina were obtained[2–4] on relatively equi-axed structures. High aspect ratios, for relatively few grains, in alumina can be obtained when there is a small amount of glass phase[6] in it, and/or by pressureless sintering of the alumina.[7]

Additions of SiC nano-particles into alumina have been shown[3] to improve the composites' wear resistance, even when equivalent grain sizes are considered for both the composite and monolithic alumina. Porosity, particularly at values $\geq 2\%$, has also been shown[8] to have a detrimental effect on wear properties. It is possible that the extra improvement, for a given grain size, induced by the addition of SiC particles could appreciably off-set the deleterious effect of porosity (above 2%) on wear. It is also possible that these additions may make it possible to use larger grain sizes for wear applications.

In this work, an in-depth study of the possibilities raised above is undertaken, with emphasis on the effect of a collection of microstructural variables on wear rate. The latter is also correlated with the materials' flexural strength.

2 MATERIALS AND EXPERIMENTAL

Monolithic alumina, and 5, 10, and 15 vol% SiC–Al_2O_3 composites were pressureless sintered. The 5 vol% SiC composite is of two types, based on the composition and particle size of the two different alumina powders (AES and AKP) used. Hence 5 AKP is the composite made from fine alumina powder, while 5 AES is that made from a relatively coarse grade. Full details of the fabricating procedure can be found in Ref. 7. However, for the

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purpose of this work the samples are divided into two groups—nearly fully dense (hereafter referred to as dense) and porous materials. The former are samples sintered to $\geq$99.6% theoretical density, and the porous materials are those fabricated to theoretical densities (TD) of between 95.1 and 99.2%. In Table 1 the characteristics of the samples are studied. The grain sizes of the porous materials, the hardness and toughness of the 5 AKP composition were determined in the present study, with the same techniques used in previous reports[7,9] by the author. Apart from W_8, the rest of the characteristics in Table 1 have been reported in these previous reports.[7,9] The flexural strength values, σ_f, were obtained from another piece of work (yet to be published) on the present materials.

The wet erosion test machine, with a rotation speed of 3 Hz, and a sweeping arm radius of 0.145 m gives a perimeter linear velocity of 2.7 m s^{-1}. Full details of the machine and the sample-mounting device can be found in Ref. 4. The sample positioning was such that the impact of eroding particles was normal to the sample surface. In 6 litres of water, 1.6 kg of SiC grits of average particle size of 780 μm were used (that is a slurry of a particle-concentration of 3.3×10^5 litre^{-1}). The grits were replenished after every 8 h (change of sample), when it was assumed their asperities might have rounded off.

The samples were final-polished to 1/4 μm, and 8 μm diamond (for just one sample) prior to wearing. The aim of the 8 μm-polish was to investigate if degree of polish affects wear rate. A total wear time of 8 h was used. This was divided into first two periods of one hour each, then followed by three periods of 2 h each. Worn samples were washed in distilled water, dried and weighed to obtain the loss of material after each period. The final wear rate, R_f (nm s^{-1}), for a total weight loss in 8 h, W_8 was obtained using the relation[2]

$$R_f = \frac{W_8}{8 \times 3600 \times A \times \rho} \tag{1}$$

where A (m^2) is the area worn in 8 h, and ρ (kgm^{-3}) is the density of the material. The area of the worn surface was calculated from its scanning electron (SE) micrograph, an example of which is shown in Fig. 1 for dense monolithic alumina. The transitory wear rates, R_t, were computed as weight loss per h.

3 RESULTS AND DISCUSSION

Wear resistance, otherwise expressed as volume of material removed (V), has been suggested[10] to be governed by the equation

$$V \propto P^{\frac{5}{4}} H^{-\frac{1}{2}} K^{-\frac{3}{4}} \tag{2}$$

where P is the applied load, H, the hardness and K the fracture toughness of the material being worn. For a constant load, such as the case in the present study, V is therefore inversely proportional to H and K.

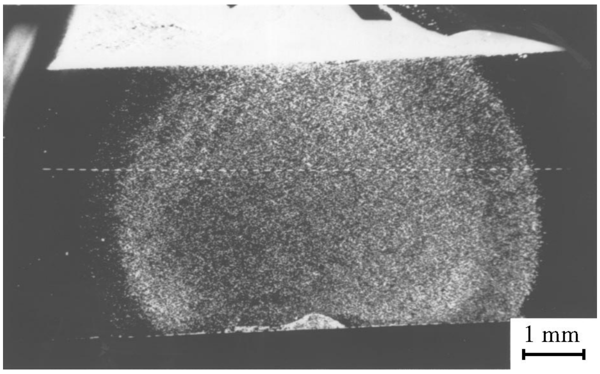


Fig. 1. SEM of the shape of dense monolithic alumina eroded for 8 h, which, at a slightly higher magnification, was used to calculate the worn area. Each of the rest of the samples had a similar shape.

Table 1. Characteristics of materials under study

Material (vol% SiC)	Class	Grain size[7] (μm)	Density[7]		Hardness[9§] (GPa)	K_{1c}[9] (MPam$^{1/2}$)	σ_f (MPa)	W_8 ($\times10^{-6}$ kg)
			(% Th.)	(g cm^{-3})				
0,Al_2O_3*	Dense	3.5±1.3	99.9	3.96	17.9±0.6	3.5±0.3	431±53	11.7
5 AKP		3.2±0.6	99.9	3.95	21.1±0.7†	4.9±0.4†	nd	5.2
5 AES		4±1.1	99.8	3.91	19.3±0.8	5.1±0.8	646±41	9.6
10 AES		2.9±0.5	99.7	3.87	20.1±0.8	5.2±0.4	560±8	4.6
15 AES		2.6±0.3	99.6	3.83	20.8±0.8	5.4±0.6	549±30	4.4
0,Al_2O_3*	Porous	6.5±1.2	96.2	3.81	nd	nd	nd	54.5
5 AKP		6.3±2.3	99.2	3.92	nd	nd	nd	8.6
10 AES		2.8±0.6	95.1	3.69	nd	nd	nd	6.2

*AES alumina powder.
†Determined in the present work.
‡Four-point bend test.
§Vickers Indentation, 10 kg load.
nd=not determined.

Interpretations of wear-resistance based on eqn 2 may not always fully reflect the level of improvement obtainable by varying several parameters on which the wear resistance of a material depends. For instance, if a proportionality constant is assumed for 5 AES and 5 AKP in Table 1, at a constant load eqn 2 suggests an improvement, in the wear resistance of 5 AKP relative to 5 AES, of only about 2.3%. However, the improvement as observed experimentally (column 8, Table 1) is about 46% (by volume). As has been suggested,[2,11] the relationship between fracture toughness (K) and microstructure is uncertain. This may be responsible for the underestimation of the level of improvement given by eqn 2.

Microstructural variables that could strongly affect wear-resistance include grain size, volume fraction of additives (in this case SiC nano-particles), porosity and aspect ratio of grains (in the present study only for alumina). Table 2, which is a summary of the final wear rates (function of both composition and porosity, is used to discuss how these variables affect wear rates. Wear mechanism, and its implication in strength/wear-resistance relationship is discussed. The effect of surface finish on transitory wear rates, R_t for the two groups of materials is also discussed.

3.1 Effect of grain size; wear rate/grain size regression equations

Table 2 indicates that irrespective of class or material, a reduction in grain size improves the wear resistance of the materials. This conforms with the results of other workers[2–4,8] on materials of similar composition.

Wear rate/grain size relationship has been described[2,11] as a function of both µm and $\mu m^{-\frac{1}{2}}$. In the present study both variants give a very good linear fit, with a correlation coefficient $(r^2)\geq 0.97$. This is most probably because the grain sizes involved are within the same range of $>2\,\mu m$. When the grain size ranges are mixed (under and above 2 µm), the situation is quite different. For instance, when the grain sizes of 1 to 12.3 µm obtained in the work of Miranda *et al.*[2] are plotted against wear rate, for µm function the fit is very poor ($r^2=0.79$), but for $\mu m^{-\frac{1}{2}}$ a good fit of 0.95 is obtained.

It may therefore be necessary to make a distinction between wear rate/grain size relationship for grains, on one hand ≥, and on the other above 2 µm. This distinction is justified since the wear mechanisms of both grain size ranges have been shown[2,3] to be dissimilar. Hence in Fig. 2 is the wear rate vs grain size (µm) plot for grains $\leq 2\,\mu m$, found in the work of Davidge *et al.*,[3] and those $>2\,\mu m$ — present work (for AES alumina powder) — on Al_2O_3/SiC "nanocomposites" of degrees of densification ≥97% theoretical density. It can be seen that as a result of the difference in wear mechanism the two ranges of grain size follow different regressional equations. Again, r^2 remains the same (0.98), irrespective of whether µm or

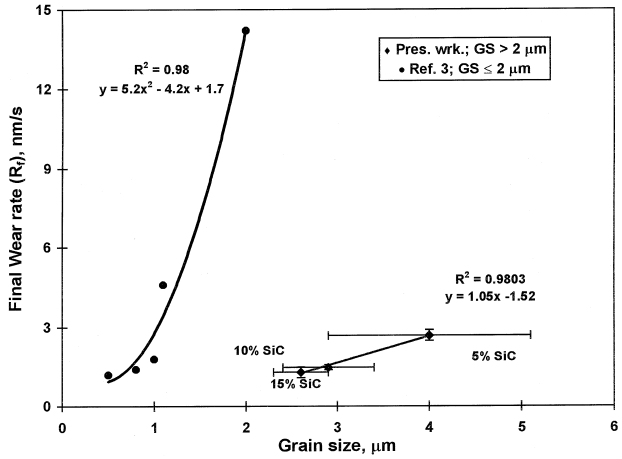


Fig. 2. Variation of wear rate with grain size (µm) for Al_2O_3–SiC "nanocomposites" of the present work and that of Ref. 3. Of significance here is the difference in the regressional equations of the two ranges of grain size. This is most probably because of the difference in wear mechanism[3] between the two ranges. The difference in wear rate between the two works is due to the higher value of particle flux in the work of Ref. 3.

Table 2. Final erosion rate (R_f) of samples

Material (vol% SiC)	Class	Grain size[7] (µm)	Density[7]		Wear rate (nm s^{-1})
			(% Th.)	(g cm^{-3})	
0,Al_2O_3*	Dense	3·5±1·3	99·9	3·96	3·2±0·3
5 AKP		3·2±0·6	99·9	3·95	1·5±0·2
5 AES		4±1·1	99·8	3·91	2·7±0·2
10 AES		2·9±0·5	99·7	3·87	1·4±0·1
15 AES		2·6±0·3	99·6	3·83	1·3±0·2
0,Al_2O_3*	Porous	6·5±1·2	96·2	3·81	7·5±0·4
5 AKP		6·3±2.3	99.2	3.92	1·9±0·2
10 AES		2·8±0·6	95·1	3·69	1·8±0·1

*AES alumina powder.

$\mu m^{-\frac{1}{2}}$ is used. However, the latter, for the range ≤ 2 mm (with a regression equation of $y = 48.8x^2 - 121.6x + 75.7$) suggests that as the grain size tends to zero the wear rate tends to an astronomically high value—a situation that is not compatible with experimental observations.

Furthermore, the distinction makes the regression equations physically significant. Hence if all the grain sizes (0.5 to 5 μm, with the density of the sample $\geq 97\%$ theoretical) from Ref. 3 are plotted against wear rate, in any format (Fig. 3) the best fit ($r^2 = 0.93$) equation is

$$y = -1.8x^2 + 13.6x - 7.5 \tag{3}$$

Not only that the best fit is poor, it can be seen that as the grain size tends towards zero the wear rate becomes negative—a situation that does not make any physical sense. However, with the distinction made (Fig. 2) it can be seen that for the range of ≤ 2 μm, as the grain size tends towards zero the wear rate tends towards 1.7 nm s^{-1}. The distinction makes the intercept of the regression equation for grains > 2 μm physically insignificant.

Although reduced grain sizes improve wear resistance, it can be seen that the slightly larger grain sized dense 5 AES composite still shows less wear (about 16%) than does monolithic alumina of about a similar degree of densification (Table 2). So the effect of additions of SiC particles appears to be more dominant than that of grain size.

3.2 Effect of additions of SiC particles

3.2.1 Effect of particles

Fine grains reduce the rate of wear, because of the delays in crack propagation at multiple boundary (found more in fine grains) junctions for re-adjustment of the direction of crack propagation.[3] The effect of particles may be more dominant than that of grain size because of their dual role of reducing grain size[7] and modifying crack paths.

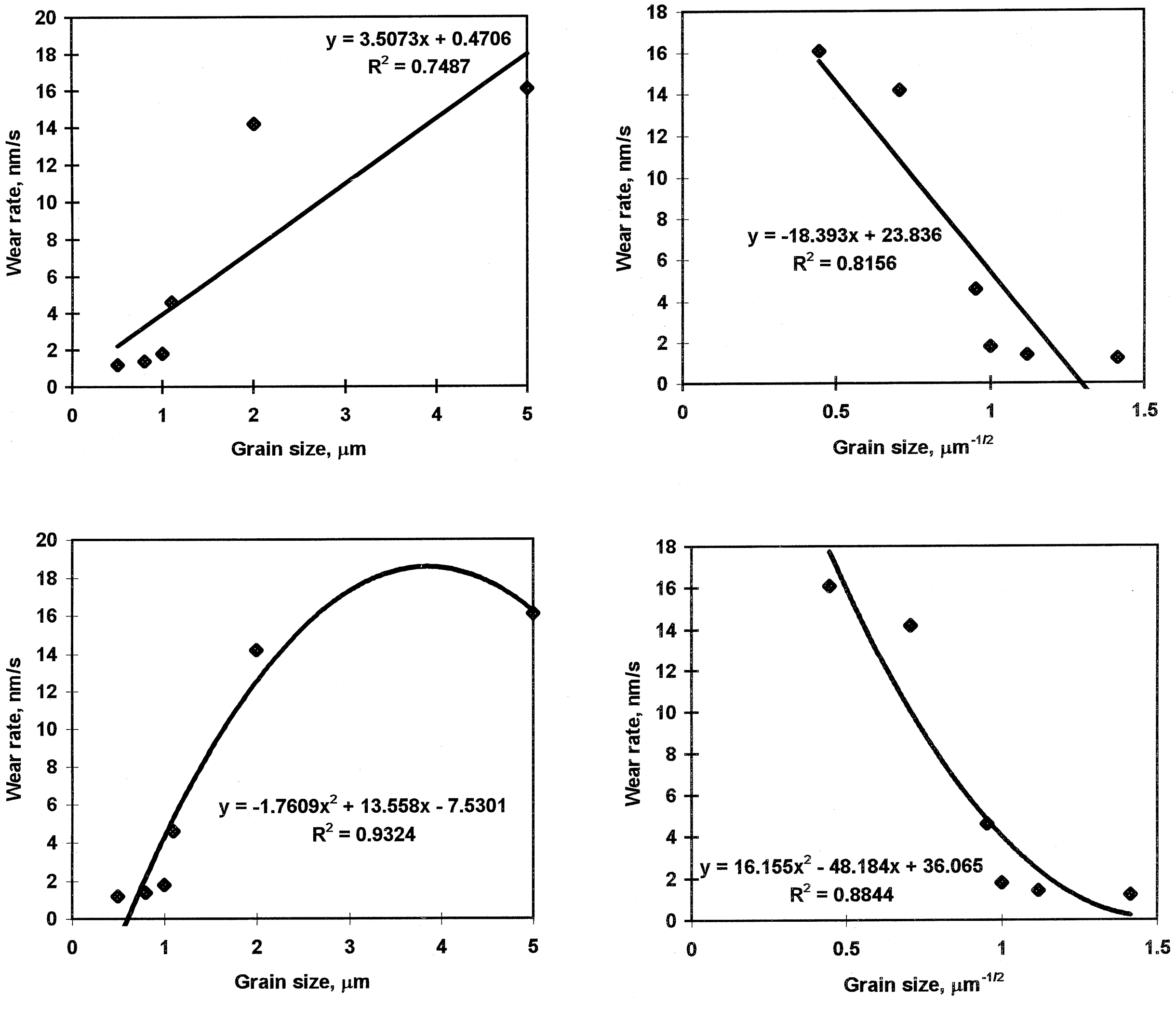
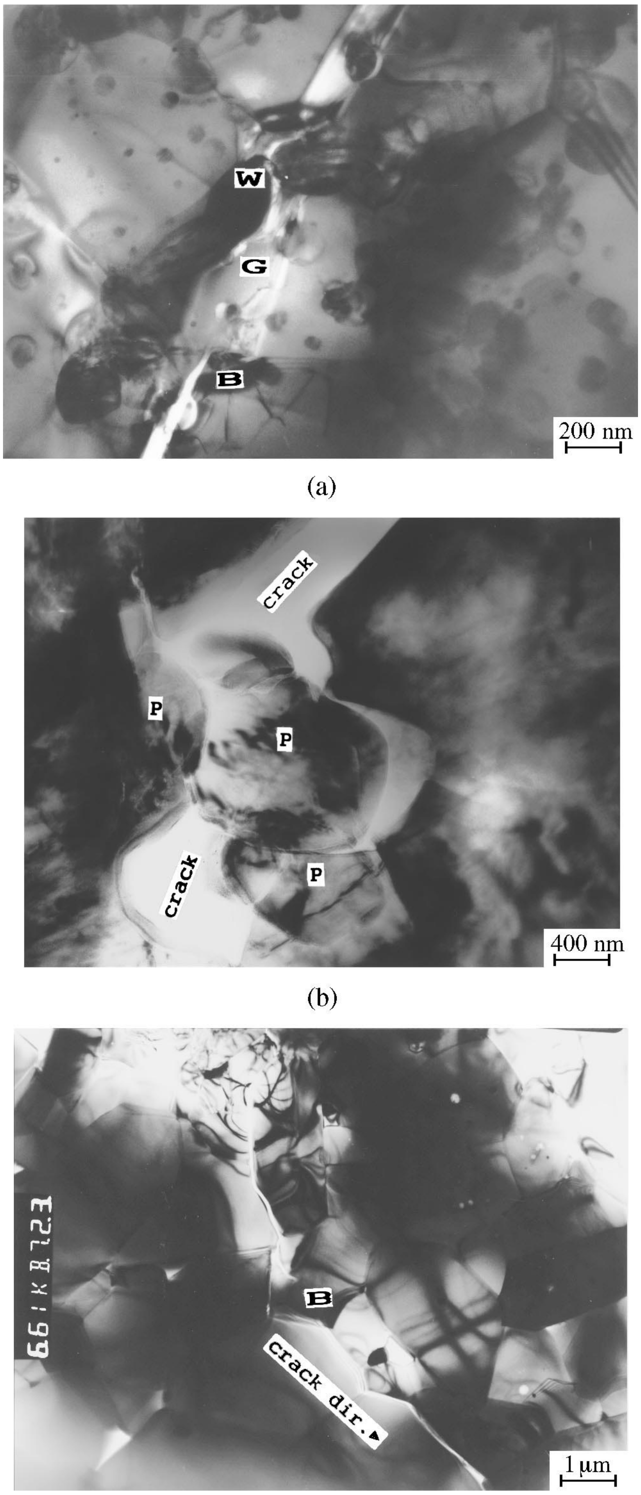


Fig. 3. Final wear rate of "nanocomposite" samples (with density $\geq 97\%$ theoretical) vs grain size for grain sizes of 0·5 to 5 μm (Ref. 3), expressed in terms of, μm, left hand side; $\mu m^{-1/2}$, right hand side; linear fit, top; quadratic fit, bottom. It can be seen that without classifying the grain sizes in terms of the wear mechanism each range ($\leq$ and > 2 μm) exhibits, a poor fit is obtained, which ever way (unlike in Fig. 2).



(a)

(b)

(c)

Fig. 4. Crack propagation restraints in (a) Al_2O_3–15% SiC composite showing deflection, wake toughening (W) and bridging (B). Note the intensity of these phenomena inside a grain (G) as small as about 1 μm; (b) composites showing a typical nanoscale bridging distance by stiff SiC particles; (c) monolithic alumina, with very few microscale bridging sites.

Figure 4, taken from a yet-to-be published work by the author, shows TEM photographs of microcracks, induced in samples by Vickers microindentation, with a load of 2 N. This level of load has been found[4,12] to be similar to that operating under the wet erosive wear conditions used here.

If it is assumed that the effect of water on crack propagation during the wet erosive wear test is the same for both monolithic alumina and composites, the latter show more restraint to crack propagation due to the effect of particles. They dissipate the energy of propagation of the cracks through various phenomena such as deflection of the cracks into the grains, wake toughening (W) and bridging (B) (Fig. 4(a)). It is noteworthy the fact that these phenomena occur even inside grains as small as about 1 μm (G). Higher magnifications reveal that the bridges are of very short distances, of the order of about 120 nm (a typical example is shown in (Fig. 4(b)). Therefore for a given area there are many more bridging sites in the composites (with stiffer SiC) than could be found in monolithic alumina (Fig. 4(c)). Damage (wear) obtains when cracks from nearby impact sites join up.[12] Also, the distribution of internal (residual) stresses, which was not investigated in this study, may partially affect the mechanics and timing of crack initiation and surface damage in the materials to the effect that the composites have an advantage over alumina. Hence a composite of a similar (or slightly larger) grain size relative to alumina would be capable of sustaining more impacts before cracks from immediate neighbouring sites could join up to lead to a damage.

3.2.2 Effect of alumina grade and volume fraction of sic particles

For about the same grain size the wear resistance of 5 AKP composite is more than double that of alumina. The magnitude of the improvement, however, depends on the type of alumina used. Hence whereas the wear resistance doubled with the AKP powder on adding 5 vol% SiC particles, only about 16% improvement was achieved with the AES powder for a similar volume fraction.

The optimum efficient addition of the particles (using the AES powder) appears to be 10 vol% (for the range of grain sizes under the present study). Above this level the change in wear rate becomes negligible.

3.3 Porosity and wear rate

In Table 2 (for porous materials), although the grain size almost doubled in alumina (relative to the dense type), it is not enough to account for the increase, by more than double, of its wear rate. Other works[2,4] on dense alumina support the last statement. On increasing the grain size from 3.6 to 8.6 μm[2] and 3.8 to 14.1 μm (almost four times),[4] the increase in wear rate was, respectively, 31 and 37%. In the present work, it can also be seen in the 5 AKP composite that a similar increase in grain size (relative to alumina) only led to about 27% deterioration of its wear resistance. Therefore porosity has a very pronounced deleterious effect on wear resistance, especially of alumina.

In the composites the deleterious effect of porosity (within the levels found in the present study) on wear rate is minimal. This can be seen in Table 2 on comparing, for instance dense and porous 10 AES composites. In the same table also, it can be seen that with 10 AES composite even showing a higher porosity level (4.9%) than that of alumina (3.8%), the former is still greater than four times more wear-resistant than the latter. It is therefore concluded that the small additions of SiC nanoparticles in alumina permit porosities (up to about 5%) that otherwise would have been intolerable in alumina as a wear-resistant material.

However, with as much as 9% porosity in 20 vol% SiC "nanocomposite" Davidge *et al.*[3] showed that the wear resistance of the composite could be impaired by more than double for a grain size of about $0.5 \pm 0.1\,\mu$m. This therefore suggests that there is a limit to which porosity is tolerable in the composites for wet erosive wear-resistance applications.

3.4 Effect of grain aspect ratio on the wear rate of alumina

The dense alumina microstructure reveals an appreciable, but limited number (about $18 \pm 2\%$) of grains of high aspect ratio (Fig. 5(a)). The porous alumina can be described as equi-axed (Fig. 5(b)). Apart from the porosity, it is likely that the higher wear rate of the porous alumina is also due to the fact that it has an equi-axed structure.

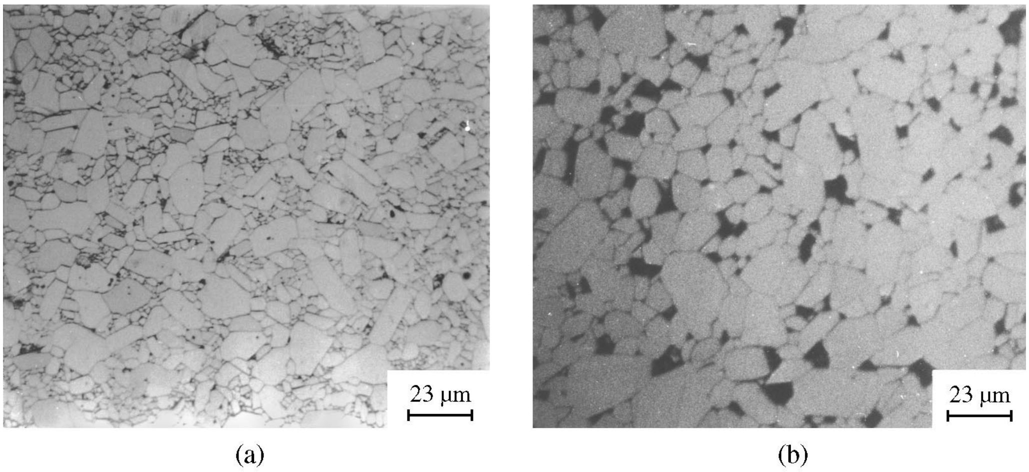
Further support to this hypothesis can be found in the work of Franco and Roberts.[4] Using the same test parameters, as in the present work, they found that equi-axed alumina structure of about 3.8 μm average grain size (with a density of $3.94\,\mathrm{g\,cm^{-3}}$) showed a wear rate of $8.4 \pm 0.8\,\mathrm{nm\,s^{-1}}$, more than double the wear rate of the dense alumina of the present work.

Although the elongated grains, by the surface area of their grain boundaries, are of low energy, it can be seen in Fig. 5(a) that they are always sandwiched by sub-micrometer grains of very high energy. It is therefore very likely that, providing the elongated (large) grains are limited in number, for similar average grain sizes, the internal energy (implicitly resistance to wear) of a bimodal structure is higher than that of equi-axed. The theory of R-curve behaviour may also be used to explain why high aspect could be favourable for wear resistance. However, as has been pointed out,[2] this is not necessarily an advantage, because critical wear events occur over very short distances.

3.5 Wear mechanism and strength/wear-resistance relationship

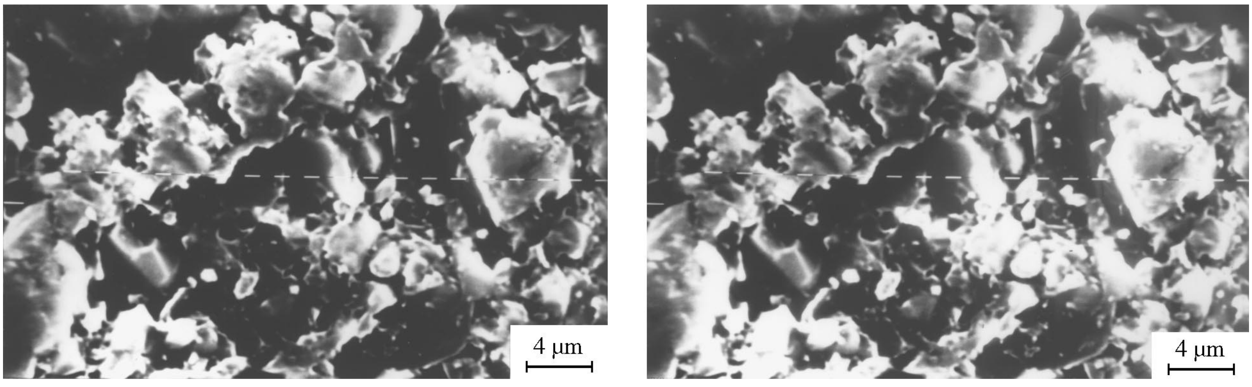
Davidge *et al.*[3] suggested that at grain sizes $> 2\,\mu$m the dominant wear mechanism appears to be grain-boundary microfracture, which leads to grain pull-outs. In Fig. 6 are the worn surfaces of monolithic alumina and 5 AES composite. It can be seen that the surfaces are the same, except that the alumina sample shows more microfracture. Thus in both alumina and composites the wear mechanism is the same.

However, the fracture surfaces (of alumina and the composites) from four-point bend tests are not the same (Fig. 7 (from the author's work yet to be published)). Whereas monolithic alumina undergoes



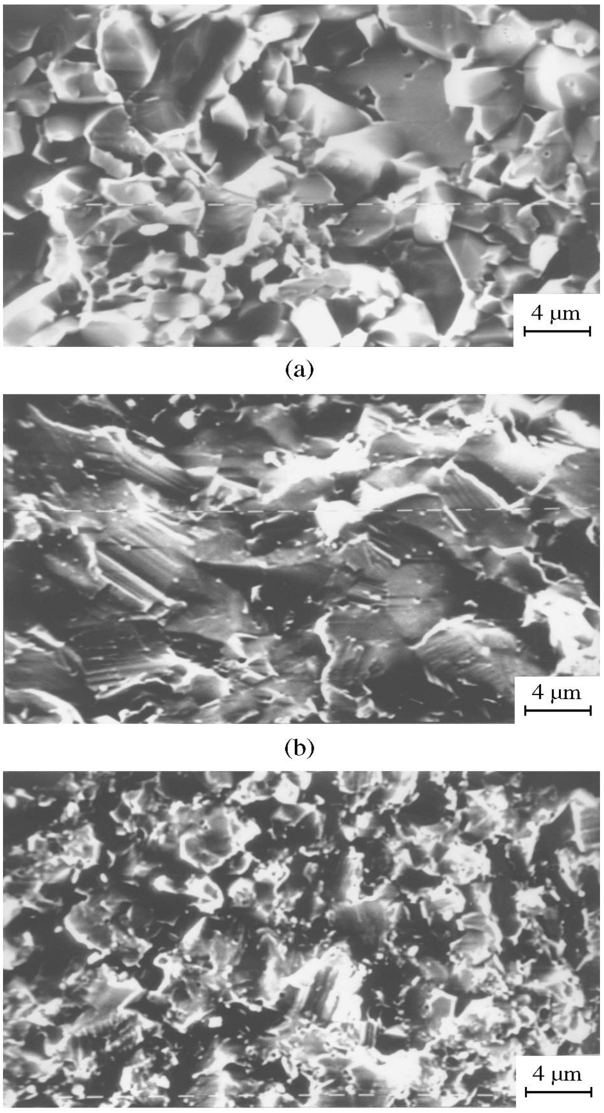
(a) (b)

Fig. 5. Optical micrographs of (a) dense, (b) porous monolithic aluminas. Note the appreciable, but limited number of grains with high aspect ratios in the dense type.



(a) (b)

Fig. 6. SE micrographs of materials worn for 8 h: (a) dense monolithic Al_2O_3, (b) 5 AES composite. The rest of the samples showed similar worn surfaces. Note that the surfaces are the same, indicating the same mechanism for the wear of alumina and composites.



(c)

Fig. 7. Fracture surfaces of materials broken at four-point bend tests: (a) monolithic Al_2O_3; (b) 5 AES; (c) 15 AES composites. Note that the surfaces are not the same, indicating different mechanisms for Al_2O_3 and composites. Note also that even between the composites 5 AES is wavier than 15 AES.

an intergranular fracture the composites fail in a transgranular manner. The latter mode of failure makes the composites to be stronger than monolithic alumina, but amongst the composites those having additions of SiC particles >5 vol% show lower strengths.[13]

It was suggested that high strength would be expected to be associated with a low wear rate.[8] This may not be the case when the wear mechanism is totally different from that which governs a macroscopic event (though related to microfracture), such as the strengthening. Hence in the present study, the reciprocal of the composites' erosion wear rate is inversely proportional with flexural strength (Fig. 8). Therefore strength, as an indicator of wear rate, may be restricted to only those materials in which both wear and strengthening phenomena are governed by the same mechanism.

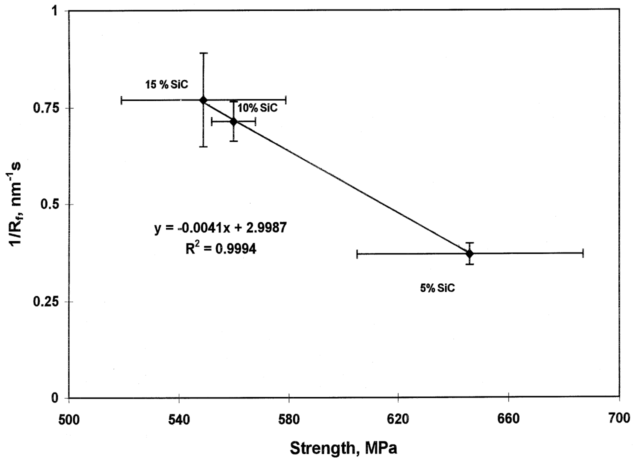


Fig. 8. Reciprocal of final erosion rate ($1/R_f$) vs strength (vol% SiC) of the "nanocomposites". Note that higher volume fractions of SiC particles improve erosion resistance, but do not lead to higher strengths.

3.6 Surface finish and transitory wear rates

"Severe" (abrasive) sliding wear shows intergranular fracture of samples, and low sliding wear rates are associated with polished and lapped alumina surfaces.[14] The latter is because surfaces in this state are not immediately disposed to either the initiation or propagation of sub-surface microcracks, which otherwise are readily favoured on ground surfaces.

Erosive and sliding types of wear are governed[14] by the same Archard equation, and going by the intergranular nature of the erosively worn surfaces of the samples in the present work, it is probable that the wear mechanism applicable here is similar to that of a "severe" sliding wear. Consequently, similar reasons for low sliding wear rates could be responsible for the low wear rates observed in the present study for the first running hour (Fig. 9). This effect is more in the composites, to the extent that some areas are virtually unworn. One such area is shown in Fig. 10—the white spots. However, apart from the virtual absence of sub-surface cracks on polished samples, the reduced wear rate in the first hour could also be explained geometrically: for two surfaces to move closer together, a pre-condition for wear to occur, a large number of higher asperities on the two surfaces need to be in contact.[14] In a polished sample the surface asperities are very low, so its contact with particles (with relatively higher asperities) is less than as would be expected for a higher amount of wear. This effect may be negligible for just a particle impact, but for a long period and multiple repetitive impacts it becomes significant.

During the second hour (Fig. 9), after the whole polished surface is destroyed, the wear rate increases, most probably because of new sub-surface cracks and better contact between the surface (now with higher asperities) and particles. Subsequently the samples maintain a wear rate approximately constant, apart from the 10 AES composites.

Normally the initial transitory wear rate, for the reasons proposed above, should always be the smallest. However, after the 8 h run the 15 AES composite showed a wear that is less than the initial one. This could be as a result of a faster reduction of the asperities (rounding-off) of the impacting particles in the presence of higher volume fraction of SiC particles in the composite, suggesting therefore that the geometrical factor proposed in the last paragraph is a strong possibility. Final and transitory wear rates for the 8 μm finish-polished sample were practically the same as those finish-polished to 1/4 μm. It is therefore not necessary to polish down to the best surface finish since polishing of any degree gives about the same result—a low initial wear rate in the early transient stages.

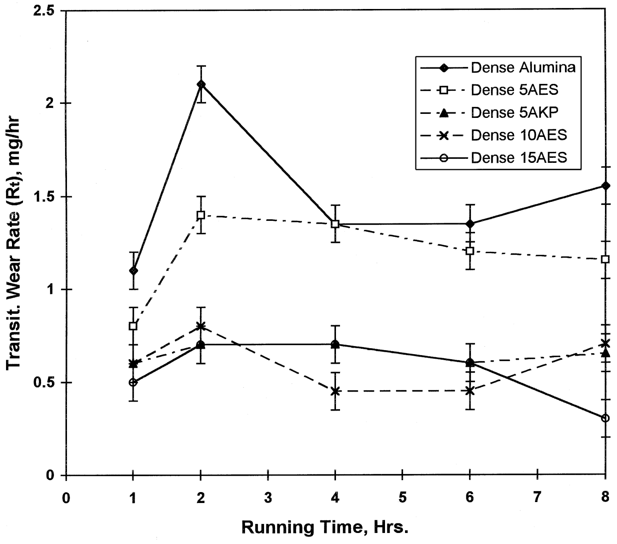


Fig. 9. Transitory erosion rate (R_t) of samples vs erosion time. Note the low erosion rate for all the materials in the first hour of erosion.

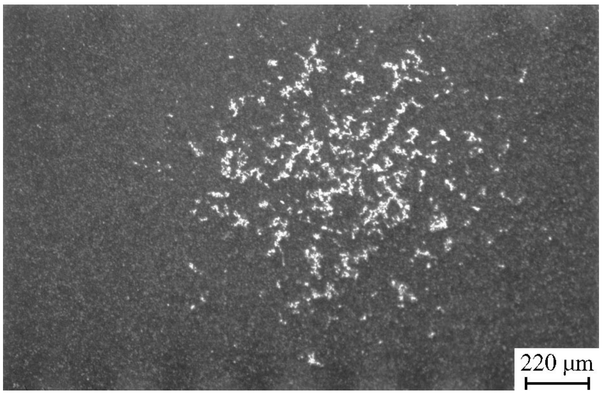


Fig. 10. Optical micrograph showing some unworn areas on the surfaces of the composite materials.

It is worthwhile considering how effective this low initial wear rate, induced by the properties of the polished surface, is in controlling the total amount of wear over a given time.

In Table 3 are periodic and total weight losses (wear) of dense and porous samples of the present work. The polished surfaces are completely damaged after about 1 h (though a time lapse of about 15 m has been reported[12] for alumina). It can be seen from this table that the weight loss within this period, for each of the dense samples (and porous alumina) is about $10 \pm 2\%$ of the total weight. For the relatively porous composite samples this is reduced to about $6 \pm 1\%$. Therefore it can be concluded that as a measure of controlling wear in this type of ceramic material, bulk properties (including microstructures) of the samples are

Table 3. Periodic and total weight losses of samples

Materials (vol% SiC)	Class	Grain size[7] (μm)	Density[7]		Weight loss (mg±≈5%[†]) After each 1 - and 2 -h runs					Total
			(%Th.)	(g cm^{-3})	1[‡] (% total)	2	4	6	8	After 8 h
0,Al_2O_3[*]	Dense	3·5±1·3	99·9	3·96	1·1 (9·4)	2·1	2·7	2·7	3·1	11·7
5 AKP		3·2±0·6	99·9	3·95	0·6 (11·5)	0·7	1·4	1·2	1·3	5·2
5 AES		4±11	99·8	3·91	0·8 (8·3)	1·4	2·7	2·4	2·3	9·6
10 AES		2·9±0·5	99·7	3·87	0·6 (13·0)	0·8	0·9	0·9	1·4	4·6
15 AES		2·6±0·3	99·6	3·83	0·5 (11·4)	0·7	1·4	1·2	0·6	4·4
0,Al_2O_3[*]	Porous	6·5±1·2	96·2	3·81	5·1 (9·4)	6·3	18·1	13·0	12·0	54·5
5 AKP		6·3±2·3	99·2	3·92	0·5 (5·8)	1·0	2·4	2·3	2·4	8·6
10 AES		2·8±0·6	95·1	3·69	0·4 (6·5)	1·0	1·4	1·7	1·7	6·2

[*] AES alumina powder.
[†] Observed error of weighing machine.
[‡] After which the polished surface is entirely damaged.

more important than the properties of polished surfaces.

4 CONCLUSIONS

- The wet erosive wear of alumina and its composites with SiC nano-particles is improved by reducing their grain sizes.
- Wear rate/grain size relationship is best described with the grain size expressed in μm instead of $\mu m^{-\frac{1}{2}}$. Owing to the fact that grain sizes above 2 μm wear following a different mechanism there is also a need to separate the grain size ranges accordingly when expressing this relationship.
- Relative to alumina the composites show better wear resistance, because of the dual role of the additions of SiC particles in refining alumina matrix grains and modifying crack paths in the composites. Modification of crack paths appears to be more rate controlling, hence a 4 μm 5 vol% SiC composite is more wear-resistant than monolithic alumina of 3.5 μm grain size.
- Porosity increases wear rate, and more so when combined with large grain sizes. However, for about similar grain size and porosity (≤5%), up to 400% improvement in wear-resistance is attainable in composites relative to alumina.
- Higher strengths in the composites may not necessarily be indicative of lower wear rates, particularly if the mechanisms that govern wear and strengthening differ.
- Monolithic alumina of a structure with a limited number (about 18 ± 2%) of grains of high aspect ratio is more wear resistant than that which is equi-axed.
- Polishing the samples can improve the initial wear-resistance of these materials, but bulk properties (including microstructure) are more rate controlling than the properties of polished surfaces.

ACKNOWLEDGEMENTS

Discussions with Dr S. G. Roberts and the financial support of ESPRC, UK, are hereby acknowledged.

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